

We claim:

1. A method for preparing an alkene from the corresponding alkane, the method comprising

5 providing an alkane or a substituted alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising (i) a major component consisting essentially of Ni, a Ni oxide, a Ni salt, or mixtures thereof, and (ii) one or more minor components consisting essentially of an element or compound selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or
10 mixtures of such elements or compounds, and
dehydrogenating the alkane to form the corresponding alkene.

2. The method of claim 1 wherein the major component consists essentially of Ni oxide.

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3. The method of claim 1 wherein one of the minor components consists essentially of an element or compound selected from the group consisting of Ti, Ta, Nb, Hf, W, Y, oxides thereof and salts thereof, or mixtures of such elements or compounds.

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4. The method of claim 1 wherein one of the minor components consists essentially of an element or compound selected from the group consisting of Ti, Ta, Nb, Hf, Y, oxides thereof and salts thereof, or mixtures of such elements or compounds.

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5. The method of claim 1 wherein one of the minor components consists essentially of an element or compound selected from the group consisting of Ti, Ta, Nb, oxides thereof and salts thereof, or mixtures of such elements or compounds.

6. The method of claim 1 wherein one of the minor components consists essentially of Ti, a Ti oxide, a Ti salt, or mixtures thereof.

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7. The method of claim 1 wherein one of the minor components consists essentially of Ta, a Ta oxide, a Ta salt, or mixtures thereof.

8. The method of claim 1 wherein one of the minor components consists
5 essentially of Nb, a Nb oxide, a Nb salt, or mixtures thereof.

9. The method of claim 1 wherein one of the minor components consists essentially of Hf, a Hf oxide, a Hf salt, or mixtures thereof.

10. The method of claim 1 wherein one of the minor components consists
10 essentially of W, a W oxide, a W salt, or mixtures thereof.

11. The method of claim 1 wherein one of the minor components consists essentially of Y, a Y oxide, a Y salt, or mixtures thereof.

12. The method of claim 1 wherein one of the minor components consists
15 essentially of Zn, a Zn oxide, a Zn salt, or mixtures thereof.

13. The method of claim 1 wherein one of the minor components consists
20 essentially of Zr, a Zr oxide, a Zr salt, or mixtures thereof.

14. The method of claim 1 wherein one of the minor components consists essentially of Al, a Al oxide, a Al salt, or mixtures thereof.

25 15. The method of claim 1 wherein the catalyst comprises (i) a major component consisting essentially of Ni oxide, and (ii) a minor component consisting essentially of Ti oxide.

16. The method of claim 1 wherein the catalyst comprises (i) a major component
30 consisting essentially of Ni oxide, and (ii) a minor component consisting essentially of Ta oxide.

17. The method of claim 1 wherein the catalyst comprises (i) a major component consisting essentially of Ni oxide, and (ii) a minor component consisting essentially of Nb oxide.

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18. The method of claim 1 wherein the catalyst comprises
a major component consisting essentially of Ni, a Ni oxide, a Ni salt, or mixtures thereof,

one or more first minor components consisting essentially of an element or
10 compound selected from the group consisting of Ti, Ta, Nb, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or mixtures of such elements or compounds, and

one or more second minor components consisting essentially of an element or
compound selected from the group consisting of a lanthanide element, a group IIIA
element, a group VA element, a group VIA element, a group IIIB element, a group IVB
15 element, a group VB element, a group VIB element, oxides thereof and salts thereof, or mixtures of such elements or compounds.

19. The method of claim 18 wherein the second minor component consists
essentially of an element or compound selected from the group consisting of La, Ce, Pr,
20 Nd, Sm, Sb, Sn, Bi, Pb, Tl, In, Te, Cr, V, Mn, Mo, Fe, Co, Cu, Ru, Rh, Pd, Pt, Ag, Cd, Os, Re, Ir, Au, Hg, oxides thereof and salts thereof, or mixtures of such elements or compounds.

20. The method of claim 18 wherein the second minor component consists
25 essentially of an element or compound selected from the group consisting of La, Ce, Pr, Nd, Sm, Sb, Sn, Bi, Co, Cr, Ag, oxides thereof and salts thereof, or mixtures of such elements or compounds.

21. The method of claim 18 wherein the catalyst further comprises a third minor
30 component, the third minor component consisting essentially of an element or compound

selected from the group consisting of an alkali metal, an alkaline earth metal, oxides thereof and salts thereof, or mixtures of such elements or compounds.

22. The method of claim 18 wherein the catalyst further comprises a third minor
5 component, the third minor component consisting essentially of an element or compound selected from the group consisting of K, Ca, Mg, oxides thereof and salts thereof, or mixtures of such elements or compounds.

23. The method of claim 1 wherein the catalyst is prepared by a method that
10 comprises

forming a pre-calcination composition by a method that includes combining a Ni-component with a first minor component, and optionally with second or third minor components,

the Ni-component consisting essentially of Ni, a Ni oxide, a Ni salt, or mixtures
15 thereof, the molar ratio of the first component ranging from about 0.1 to about 0.96,

the first minor component consisting essentially of elements or compounds selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof, and salts thereof, or mixtures of such elements or compounds, the molar ratio of the second component ranging from about 0.04 to about 0.8

the second minor component consisting essentially of an element or compound
20 selected from the group consisting of a lanthanide element, a group IIIA element, a group VA element, a group VIA element, a group IIIB element, a group IVB element, a group VB element, a group VIB element, oxides thereof, and salts thereof, or mixtures of such elements or compounds, the molar ratio of the third component ranging from 0 to about
25 0.5,

the third minor component consisting essentially of an element or compound selected from the group consisting of an alkali metal, an alkaline earth metal, oxides thereof and salts thereof, or mixtures of such elements or compounds, the molar ratio of the fourth component ranging from 0 to about 0.5, and

30 calcining the pre-calcination composition.

24. The method of claim 1 wherein a C₂ to C₆ alkane or substituted C₂ to C₆ alkane is provided to the reaction zone and dehydrogenated therein.

25. The method of claim 1 wherein a C₂ to C₄ alkane is provided to the reaction
5 zone and dehydrogenated therein.

26. The method of claim 1 wherein a substituted C₂ to C₄ alkane is provided to the reaction zone and dehydrogenated therein.

10 27. The method of claims 1, 15, 16 or 17 wherein the alkane is ethane.

28. The method of claims 1, 15, 16 or 17 wherein the alkane is propane.

29. The method of claims 1, 15, 16 or 17 wherein the alkane is isopropanol.

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30. The method of claims 1, 15, 16 or 17 wherein the alkane is n-butane.

31. The method of claims 1, 15, 16 or 17 wherein the alkane is isobutane.

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32. The method of claims 1, 15, 16 or 17 wherein the alkane is ethyl chloride.

33. The method of claims 1, 15, 16 or 17 wherein the alkane is isopentane.

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34. The method of claims 1, 15, 16 or 17 wherein the gaseous oxidant comprises molecular oxygen.

35. The method of claims 1, 15, 16 or 17 wherein the gaseous oxidant is air, inert-diluted air, or oxygen-enriched air.

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36. The method of claim 1 wherein the reaction zone is maintained at a temperature ranging from about 200 °C to about 400 °C.

37. The method of claims 1, 15, 16 or 17 wherein the reaction zone is maintained at a temperature of less than about 300 °C.

5 38. The method of claims 1, 15, 16 or 17 wherein the catalyst is a supported catalyst.

39. The method of claims 1, 15, 16 or 17 wherein the catalyst is supported on a material selected from the group consisting of silica, alumina, zeolite, activated carbon,
10 titania, zirconia and magnesia.

40. The method of claims 1, 15, 16 or 17 wherein the alkane is oxidatively dehydrogenated to form the corresponding alkene with an alkane conversion of at least about 10% and an alkene selectivity of at least about 70%.

15 41. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising Ni oxide and Ti oxide,
20 and

dehydrogenating the alkane to form the corresponding alkene.

42. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

25 providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising Ni oxide and Ta oxide, and

dehydrogenating the alkane to form the corresponding alkene.

30 43. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising Ni oxide and Nb oxide, and

dehydrogenating the alkane to form the corresponding alkene.

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44. The methods of claims 41, 42 or 43 wherein the catalyst is a supported catalyst, the alkane is selected from the group consisting of ethane, propane, isobutane, n-butane and ethyl chloride, the gaseous oxidant is molecular oxygen, and the reaction zone is maintained at a temperature ranging from about 200 °C to about 400 °C.

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45. The methods of claims 41, 42 or 43 wherein the catalyst is a supported catalyst, the alkane is ethane, the gaseous oxidant is molecular oxygen, the reaction zone is maintained at a temperature ranging from about 250 °C to about 350 °C, and the ethane is oxidatively dehydrogenated to form ethylene with an ethane conversion of at least about 10% and an ethylene selectivity of at least about 70%.

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46. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a material comprising a compound having the formula (I)

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dehydrogenating the alkane to form the corresponding alkene, where

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A is an element selected from the group consisting of Ti, Ta, Nb, Hf, W, Y, Zn, Zr, Al, and mixtures of two or more thereof,

B is an element selected from the group consisting of a lanthanide element, a group IIIA element, a group VA element, a group VIA element, a group IIIB element, a group IVB element, a group VB element, a group VIB element, and mixtures of two or more thereof,

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C is an alkali metal, an alkaline earth metal or mixtures thereof,

x is a number ranging from about 0.1 to about 0.96, a is a number ranging from about 0.04 to about 0.8, b is a number ranging from 0 to about 0.5, c is a number ranging from 0 to about 0.5, and d is a number that satisfies valence requirements.

5 47. The method of claim 46 wherein A is an element selected from the group consisting of Ti, Ta, Nb and mixtures of two or more thereof.

48. The method of claim 46 wherein A is a mixture of Ti and Ta.

10 49. The method of claim 46 wherein A is a mixture of Ti and Nb.

50. The method of claim 46 wherein A is a mixture of Ta and Nb.

51. The method of claim 46 wherein A is Ti.

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52. The method of claim 46 wherein A is Ta.

53. The method of claim 46 wherein A is Nb.

20 54. The method of claim 46 wherein B is selected from the group consisting of La, Ce, Pr, Nd, Sm, Sb, Sn, Bi, Pb, Tl, In, Te, Cr, V, Mn, Mo, Fe, Co, Cu, Ru, Rh, Pd, Pt, Ag, Cd, Os, Re, Ir, Au, Hg and mixtures of two or more thereof.

25 55. The method of claims 46 or 47 wherein B is selected from the group consisting of La, Ce, Pr, Nd, Sm, Sb, Sn, Bi, Co, Cr, Ag and mixtures of two or more thereof.

56. The method of claim 46 wherein C is selected from the group consisting of K, Mg, Ca and mixtures of two or more thereof

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57. The method of claims 46, 47, 48, 49, 50, 51, 52 or 53 wherein B is selected from the group consisting of La, Ce, Pr, Nd, Sm, Sb, Sn, Bi, Co, Cr, Ag and mixtures of two or more thereof, and C is selected from the group consisting of K, Mg, Ca and mixtures of two or more thereof.

5 58. The method of claim 46 wherein x is a number ranging from about 0.3 to about 0.85, a is a number ranging from about 0.04 to about 0.5, b is a number ranging from 0 to about 0.1, c is a number ranging from 0 to about 0.1, and d is a number that satisfies valence requirements.

10 59. The method of claim 47 wherein B is selected from the group consisting of La, Ce, Pr, Nd, Sm, Sb, Sn, Bi, Co, Cr, Ag and mixtures of two or more thereof, C is selected from the group consisting of K, Mg, Ca and mixtures of two or more thereof, x is a number ranging from about 0.5 to about 0.8, a is a number ranging from about 0.1 to
15 about 0.5, b is a number ranging from 0 to about 0.1, c is a number ranging from 0 to about 0.1, and d is a number that satisfies valence requirements.

60. The method of claim 51 wherein x is a number ranging from about 0.6 to about 0.8, a is a number ranging from about 0.3 to about 0.4, b is a number ranging from
20 0 to about 0.05, c is a number ranging from 0 to about 0.05, and d is a number that satisfies valence requirements.

61. The method of claim 52 wherein x is a number ranging from about 0.6 to about 0.8, a is a number ranging from about 0.3 to about 0.4, b is a number ranging from
25 0 to about 0.05, c is a number ranging from 0 to about 0.05, and d is a number that satisfies valence requirements.

62. The method of claim 53 wherein x is a number ranging from about 0.6 to about 0.8, a is a number ranging from about 0.3 to about 0.4, b is a number ranging from
30 0 to about 0.05, c is a number ranging from 0 to about 0.05, and d is a number that satisfies valence requirements.

63. The method of claims 46 or 47 wherein b and c are each zero, whereby the reaction zone contains a material comprising a compound having the formula I-A:
 $\text{Ni}_x\text{A}_a\text{O}_d$ (I-A).

64. The method of claim 46 wherein the reaction zone contains a material comprising a compound having the formula (II)



La^* is one or more lanthanide series elements selected from the group consisting of La_m , Ce_n , Pr_o , Nd_p , Sm_q ,

x is a number ranging from about 0.1 to about 0.96,

j, k and l are each numbers ranging from 0 to about 0.8 and the sum of (j + k + l) is at least about 0.04,

m, n, o, p, q, r, s and t are each numbers ranging from 0 to about 0.1, and the sum of (m + n + o + p + q + r + s + t) is at least about 0.005,

u, v and w are each numbers ranging from 0 to about 0.1, and

d is a number that satisfies valence requirements.

65. The method of claim 64 wherein the sum of (j + k + l) ranges from about 0.04 to about 0.5.

66. The method of claim 64 wherein one of j, k and l are zero, two of j, k and l are greater than zero, and the sum of (j + k + l) ranges from about 0.1 to about 0.4.

67. The method of claim 64 wherein each of j, k and l are greater than zero and the sum of (j + k + l) ranges from about 0.1 to about 0.4.

68. The method of claim 64 wherein the sum of (m + n + o + p + q + r + s + t) ranges from about 0.005 to about 0.1.

69. The method of claim 64 wherein the sum of $(u + v + w)$ is at least about 0.005.

5 70. The method of claim 64 wherein the sum of $(u + v + w)$ ranges from about 0.005 to about 0.1.

71. The method of claim 64 the sum of $(j + k + l)$ ranges from about 0.1 to about 0.4, the sum of $(m + n + o + p + q + r + s + t)$ ranges from about 0.005 to about 0.1, and
10 the sum of $(u + v + w)$ ranges from about 0.005 to about 0.1.

72. The methods of claims 46, 47 or 64 wherein the reaction zone is maintained at a temperature of less than about 300 °C.

15 73. The methods of claims 46, 47 or 64 wherein the alkane is oxidatively dehydrogenated to form the corresponding alkene with an alkane conversion of at least about 10% and an alkene selectivity of at least about 70%.

74. The methods of claims 46, 47 or 64 wherein the catalyst is a supported
20 catalyst, the alkane is selected from the group consisting of ethane, propane, isobutane, n-butane and ethyl chloride, the gaseous oxidant is molecular oxygen, and the reaction zone is maintained at a temperature ranging from about 200 °C to about 400 °C.

75. The methods of claims 46, 47 or 64 wherein the catalyst is a supported
25 catalyst, the alkane is ethane, the gaseous oxidant is molecular oxygen, the reaction zone is maintained at a temperature ranging from about 250 °C to about 350 °C, and the ethane is oxidatively dehydrogenated to form ethylene with an ethane conversion of at least about 10% and an ethylene selectivity of at least about 70%.

30 76. A method for preparing a C_2 to C_4 alkene from the corresponding alkane, the method comprising

providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising (i) a Ni oxide, and (ii) an oxide of an element selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, and Al, and

5 dehydrogenating the alkane to form the corresponding alkene with an alkane conversion of at least about 10% and an alkene selectivity of at least about 70%.

77. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

10 providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a calcination product of a composition comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) an element or compound selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or mixtures of such elements or compounds, and

15 dehydrogenating the alkane to form the corresponding alkene with an alkane conversion of at least about 10% and an alkene selectivity of at least about 70%.

78. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

20 (a) co-feeding a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising a calcination product of a composition comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) an element or compound selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or mixtures of such elements or

25 compounds, the catalyst being at temperature ranging from about 200 °C to about 500 °C,

 (b) contacting the alkane with the catalyst in the presence of the gaseous oxidant to dehydrogenate the alkane to form the corresponding alkene,

 (c) removing alkene, unreacted alkane and unreacted gaseous oxidant from the reaction zone, and

30 (d) effecting steps (a), (b) and (c) for a cumulative reaction period of not less than about 200 hours.

79. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

co-feeding a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising a calcination product of a composition comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) an element or compound selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or mixtures of such elements or compounds,

contacting the alkane with the catalyst in the presence of the gaseous oxidant to dehydrogenate the alkane to form the corresponding alkene,

controlling the temperature of the reaction zone to be less than about 300 °C.

80. A method for preparing ethylene from ethane, the method comprising

providing ethane and molecular oxygen to a reaction zone containing a catalyst, the catalyst being a calcination product of a composition comprising (i) a major component consisting essentially of Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) a minor component consisting essentially of an element or compound selected from the group consisting of Ti, Ta, Nb, oxides thereof and salts thereof, or mixtures of such elements or compounds,

maintaining the reaction zone at a temperature ranging from about 275 °C to about 325 °C, and

oxidatively dehydrogenating the ethane to form ethylene with an ethane conversion of at least about 10% and an ethylene selectivity of at least about 70%.

81. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising Ni, a Ni oxide, a Ni salt or mixtures thereof, and

oxidatively dehydrogenating the alkane to form the corresponding alkene in the reaction zone, the reaction zone comprising the corresponding alkene in a molar concentration of at least about 5 %, relative to total moles of hydrocarbon, during the oxydehydrogenation, the alkane conversion being at least about 5 %, and the alkene selectivity being at least about 50 %.

82. The method of claim 81 wherein the alkane and the gaseous oxidant are co-fed to the reaction zone, the method further comprising
co-feeding a C₂ to C₄ alkene corresponding to the alkane to the reaction zone.

83. The method of claim 81 wherein the alkane and the gaseous oxidant are co-fed to the reaction zone, the method further comprising
exhausting a product stream comprising the corresponding alkene and unreacted alkane from the reaction zone, and
recycling at least a portion of the alkene- and unreacted-alkane-containing product stream to the reaction zone.

84. The method of claim 81 wherein the catalyst comprises (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) an element or compound selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or mixtures of such elements or compounds.

85. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising
feeding a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane to a first reaction zone containing a catalyst, the catalyst comprising a calcination product of a composition comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) an element or compound selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or mixtures of such elements or compounds,
co-feeding a gaseous oxidant to the first reaction zone,

dehydrogenating the alkane to form the corresponding alkene in the first reaction zone,

exhausting a product stream comprising the corresponding alkene and unreacted alkane from the first reaction zone,

5 feeding the alkene- and unreacted-alkane-containing product stream from the first reaction zone to a second reaction zone,

co-feeding a gaseous oxidant to the second reaction zone,

dehydrogenating the alkane to form the corresponding alkene in the second reaction zone.

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86. The method of claim 85 wherein the concentration of oxygen in the first and second reaction zones is controlled to obtain an overall alkane conversion of at least about 5 % and an overall alkene selectivity of at least about 50 %.

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87. The method of claim 85 wherein the molar concentration of oxygen in the first and second reaction zones ranges from about 3 % to about 20 %, in each case relative to ethane.

88. The method of claim 85 wherein the second reaction zone comprises the
20 corresponding alkene at a molar concentration of at least about 5 %, relative to total moles of hydrocarbon.

89. The method of claim 85 wherein the alkane is oxidatively dehydrogenated in the first reaction zone to form the corresponding alkene with an alkane conversion of at
25 least about 10% and an alkene selectivity of at least about 70%.

90. The method of claim 85 wherein the alkane is oxidatively dehydrogenated in the second reaction zone to form the corresponding alkene with an alkane conversion of at least about 5% and an alkene selectivity of at least about 50%.

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91. The method of claim 85 wherein the alkane is oxidatively dehydrogenated in the first reaction zone to form the corresponding alkene with an alkane conversion of at least about 10% and an alkene selectivity of at least about 70%, the second reaction zone comprises the corresponding alkene in a molar concentration of at least about 5 %, relative to total moles of hydrocarbon, and the alkane is oxidatively dehydrogenated in the second reaction zone to form the corresponding alkene with an alkane conversion of at least about 5% and an alkene selectivity of at least about 50%.

92. A mixed-metal oxide composition comprising a compound represented by Formula I



where

A is an element selected from the group consisting of Ti, Ta, Nb, Hf, W, Y, Zn, Zr, Al, and mixtures of two or more thereof,

B is an element selected from the group consisting of a lanthanide element, a group IIIA element, a group VA element, a group VIA element, a group IIIB element, a group IVB element, a group VB element, a group VIB element, and mixtures of two or more thereof,

C is an alkali metal, an alkaline earth metal or mixtures thereof,

x is a number ranging from about 0.1 to about 0.96, a is a number ranging from about 0.04 to about 0.8, b is a number ranging from 0 to about 0.5, c is a number ranging from 0 to about 0.5, and d is a number that satisfies valence requirements.

93. The mixed-metal oxide composition of claim 92 wherein the compound is represented by the Formula II



La* is one or more lanthanide series elements selected from the group consisting of La_m, Ce_n, Pr_o, Nd_p, Sm_q,

x is a number ranging from about 0.1 to about 0.96,

j, k and l are each numbers ranging from 0 to about 0.8 and the sum of (j + k + l)

5 is at least about 0.04,

m, n, o, p, q, r, s and t are each numbers ranging from 0 to about 0.1, and the sum of (m + n + o + p + q + r + s + t) is at least about 0.005,

u, v and w are each numbers ranging from 0 to about 0.1, and

d is a number that satisfies valence requirements.

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94. A composition of matter comprising a compound resulting from the steps of forming a pre-calcination composition comprising a compound represented by Formula IIA

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$$\text{Ni}_x\text{Ti}_j\text{Ta}_k\text{Nb}_l\text{La}^*\text{Sb}_r\text{Sn}_s\text{Bi}_t\text{Ca}_u\text{K}_v\text{Mg}_w \quad (\text{IIA}), \text{ where}$$

La* is one or more lanthanide series elements selected from the group consisting of La_m, Ce_n, Pr_o, Nd_p, Sm_q,

x is a number ranging from about 0.1 to about 0.96,

20 j, k and l are each numbers ranging from 0 to about 0.8 and the sum of (j + k + l) is at least about 0.04,

m, n, o, p, q, r, s and t are each numbers ranging from 0 to about 0.1, and the sum of (m + n + o + p + q + r + s + t) is at least about 0.005,

25 u, v and w are each numbers ranging from 0 to about 0.1, and d is a number that satisfies valence requirements, and

calcining the pre-calcination composition.

95. A mixed-metal oxide catalyst comprising Ni, a Ni oxide, a Ni salt or mixtures thereof, and

an element or compound selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or mixtures of such elements or compounds,

the mixed-metal oxide catalyst being capable of converting at least about 5 % of a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane to the corresponding alkene with an alkane conversion of at least about 10% and an alkene selectivity of at least about 70 % in a reaction zone comprising at least about 5 % of the corresponding alkene.

96. A method for preparing a catalyst composition, the method comprising forming a pre-calcination composition comprising a compound represented by Formula I-B



where

A is an element selected from the group consisting of Ti, Ta, Nb, Hf, W, Y, Zn, Zr, Al, and mixtures of two or more thereof,

B is an element selected from the group consisting of a lanthanide element, a group IIIA element, a group VA element, a group VIA element, a group IIIB element, a group IVB element, a group VB element, a group VIB element, and mixtures of two or more thereof,

C is an alkali metal, an alkaline earth metal or mixtures thereof,

x is a number ranging from about 0.1 to about 0.96, a is a number ranging from about 0.04 to about 0.8, b is a number ranging from 0 to about 0.5, and c is a number ranging from 0 to about 0.5, and calcining the pre-calcination composition.

97. The method of claim 96 wherein the pre-calcination composition comprises a compound represented by Formula II-B



La* is one or more lanthanide series elements selected from the group consisting of La_m, Ce_n, Pr_o, Nd_p, Sm_q,

x is a number ranging from about 0.1 to about 0.96,

5 j, k and l are each numbers ranging from 0 to about 0.8 and the sum of (j + k + l) is at least about 0.04,

m, n, o, p, q, r, s and t are each numbers ranging from 0 to about 0.1, and the sum of (m + n + o + p + q + r + s + t) is at least about 0.005,

10 u, v and w are each numbers ranging from 0 to about 0.1, and d is a number that satisfies valence requirements, and calcining the pre-calcination composition.

98. A method for preparing a catalyst, the method comprising

forming a pre-calcination composition by a method that includes combining a Ni-
15 component with a first minor component, and optionally with second and third minor components,

the Ni-component consisting essentially of Ni, a Ni oxide, a Ni salt, or mixtures thereof, the molar ratio of the first component ranging from about 0.1 to about 0.96,

20 the first minor component consisting essentially of elements or compounds selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof, and salts thereof, or mixtures of such elements or compounds, the molar ratio of the second component ranging from about 0.04 to about 0.8

the second minor component consisting essentially of an element or compound selected from the group consisting of a lanthanide element, a group IIIA element, a group
25 VA element, a group VIA element, a group IIIB element, a group IVB element, a group VB element, a group VIB element, oxides thereof, and salts thereof, or mixtures of such elements or compounds, the molar ratio of the third component ranging from 0 to about 0.5,

30 the third minor component consisting essentially of an element or compound selected from the group consisting of an alkali metal, an alkaline earth metal, oxides

thereof and salts thereof, or mixtures of such elements or compounds, the molar ratio of the fourth component ranging from 0 to about 0.5, and calcining the pre-calcination composition.

5 99. A method for preparing a downstream reaction product of ethylene, the method comprising

 oxidatively dehydrogenating ethane in the presence of a catalyst to form ethylene, the catalyst comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) elements or compounds selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, 10 Zn, Zr, Al, oxides thereof, and salts thereof, or mixtures of such elements or compounds, and

 reacting the ethylene to form the downstream reaction product.

100. The method of claim 99 wherein ethane is oxidatively dehydrogenated to form 15 ethylene according to the method of claims 1, 23, 46, 76 or 80.

101. The method of claim 99 wherein the downstream reaction product is selected from the group consisting of polyethylene, styrene, ethanol, acetaldehyde, acetic acid, vinyl chloride, ethylene oxide, ethylene glycol, ethylene carbonate, ethyl acetate and 20 vinyl acetate, and the reaction step is selected, correspondingly, from the group consisting of:

 polymerizing the ethylene to form polyethylene,
 reacting the ethylene with benzene to form styrene, directly or indirectly through an ethylbenzene intermediate,

25 hydrating the ethylene to form ethanol,
 oxidizing the ethylene to form acetaldehyde,
 hydrating the ethylene to form ethanol and then oxidizing the ethanol to form acetaldehyde,

 oxidizing the ethylene to form acetic acid,

30 chlorinating or oxychlorinating the ethylene to form vinyl chloride,

 oxidizing ethylene to form ethylene oxide,

oxidizing ethylene to form ethylene glycol,
oxidizing ethylene to form ethylene oxide, and hydrating the ethylene oxide to
form ethylene glycol,
oxidizing ethylene to form ethylene carbonate, directly or indirectly through an
5 ethylene oxide intermediate,
reacting the ethylene with acetic acid to form ethyl acetate,
reacting the ethylene with acetic acid to form vinyl acetate.

102. A method for preparing a downstream reaction product of propylene, the
10 method comprising
oxidatively dehydrogenating propane in the presence of a catalyst to form
propylene, the catalyst comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and
(ii) elements or compounds selected from the group consisting of Ti, Ta, Nb, Hf, W, Y,
Zn, Zr, Al, oxides thereof, and salts thereof, or mixtures of such elements or compounds,
15 and
reacting the propylene to form the downstream reaction product.

103. The method of claim 102 wherein propane is oxidatively dehydrogenated to
form propylene according to the method of claims 1, 23, 46 or 76.

20

104. The method of claim 102 wherein the downstream reaction product is selected
from the group consisting of polypropylene, propylene oxide, propylene carbonate,
acrolein, acrylic acid and acetone, and the reaction step is selected, correspondingly, from
the group consisting of:

25 polymerizing the propylene to form polypropylene,
oxidizing the propylene to form propylene oxide,
oxidizing the propylene to form propylene carbonate, directly or through a
propylene oxide intermediate,
oxidizing the propylene to form acrolein,
30 oxidizing the propylene to form acrylic acid, and
oxidizing the propylene to form acetone.

105. A method for preparing a downstream reaction product of butane, the method comprising

oxidatively dehydrogenating a butane in the presence of a catalyst to form
5 a butene, the catalyst comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) elements or compounds selected from the group consisting of Ti, Ta, Nb, Hf, W, Y, Zn, Zr, Al, oxides thereof, and salts thereof, or mixtures of such elements or compounds, and reacting the butane to form the downstream reaction product.

10 106. The method of claim 105 wherein isobutane is oxidatively dehydrogenated to form isobutylene according to the method of claims 1, 23, 46 or 76.

107. The method of claim 105 wherein the downstream reaction product is selected from the group consisting of butanol, methacrylic acid, butadiene, butanediol,
15 methylethylketone, methylvinylketone, furane, and crotonaldehyde, and the reaction step is selected, correspondingly, from the group consisting of:

hydrating butene to form butanol,

oxidizing isobutene to form methacrylic acid,

dehydrogenating n-butene to form butadiene,

20 dehydrogenating n-butene to form butadiene, and then hydrating the butadiene to form butanediol,

dehydrogenating n-butene to form butadiene, and then oxidizing the butadiene to form methylethylketone,

oxidizing n-butene to form methylethylketone,

25 dehydrogenating n-butene to form butadiene, and then oxidizing the butadiene to form methylvinylketone,

oxidizing n-butene to form methylvinylketone,

oxidizing n-butene to form furane, and

30 dehydrogenating n-butene to form butadiene, and then oxidizing butadiene to form crotonaldehyde.

37. The method of claims 1, 15, 16 or 17 wherein the reaction zone is maintained at a temperature of less than about 300 °C.

5 38. The method of claims 1, 15, 16 or 17 wherein the catalyst is a supported catalyst.

39. The method of claims 1, 15, 16 or 17 wherein the catalyst is supported on a material selected from the group consisting of silica, alumina, zeolite, activated carbon,
10 titania, zirconia and magnesia.

40. The method of claims 1, 15, 16 or 17 wherein the alkane is oxidatively dehydrogenated to form the corresponding alkene with an alkane conversion of at least about 10% and an alkene selectivity of at least about 70%.

15 41. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising
providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising Ni oxide and Ti oxide,
20 and
dehydrogenating the alkane to form the corresponding alkene.

42. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising
25 providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising Ni oxide and Ta oxide,
and
dehydrogenating the alkane to form the corresponding alkene.

30 43. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising Ni oxide and Nb oxide, and

dehydrogenating the alkane to form the corresponding alkene.

5

44. The methods of claims 41, 42 or 43 wherein the catalyst is a supported catalyst, the alkane is selected from the group consisting of ethane, propane, isobutane, n-butane and ethyl chloride, the gaseous oxidant is molecular oxygen, and the reaction zone is maintained at a temperature ranging from about 200 °C to about 400 °C.

10

45. The methods of claims 41, 42 or 43 wherein the catalyst is a supported catalyst, the alkane is ethane, the gaseous oxidant is molecular oxygen, the reaction zone is maintained at a temperature ranging from about 250 °C to about 350 °C, and the ethane is oxidatively dehydrogenated to form ethylene with an ethane conversion of at least about 10% and an ethylene selectivity of at least about 70%.

15

46. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant

20 to a reaction zone containing a material comprising a compound having the formula (I)



dehydrogenating the alkane to form the corresponding alkene, where

25 A is an element selected from the group consisting of Ti, Ta, Nb, Hf, W, Y, Zn, Zr, Al, and mixtures of two or more thereof,

B is an element selected from the group consisting of a lanthanide element, a group IIIA element, a group VA element, a group VIA element, a group IIIB element, a group IVB element, a group VB element, a group VIB element, and mixtures of two or more thereof,

30

C is an alkali metal, an alkaline earth metal or mixtures thereof,

x is a number ranging from about 0.1 to about 0.96, a is a number ranging from about 0.04 to about 0.8, b is a number ranging from 0 to about 0.5, c is a number ranging from 0 to about 0.5, and d is a number that satisfies valence requirements.

5 47. The method of claim 46 wherein A is an element selected from the group consisting of Ti, Ta, Nb and mixtures of two or more thereof.

48. The method of claim 46 wherein A is a mixture of Ti and Ta.

10 49. The method of claim 46 wherein A is a mixture of Ti and Nb.

50. The method of claim 46 wherein A is a mixture of Ta and Nb.

51. The method of claim 46 wherein A is Ti.

15

52. The method of claim 46 wherein A is Ta.

53. The method of claim 46 wherein A is Nb.

20 54. The method of claim 46 wherein B is selected from the group consisting of La, Ce, Pr, Nd, Sm, Sb, Sn, Bi, Pb, Tl, In, Te, Cr, V, Mn, Mo, Fe, Co, Cu, Ru, Rh, Pd, Pt, Ag, Cd, Os, Re, Ir, Au, Hg and mixtures of two or more thereof.

55. The method of claims 46 or 47 wherein B is selected from the group
25 consisting of La, Ce, Pr, Nd, Sm, Sb, Sn, Bi, Co, Cr, Ag and mixtures of two or more thereof.

56. The method of claim 46 wherein C is selected from the group consisting of K, Mg, Ca and mixtures of two or more thereof

30

57. The method of claims 46, 47, 48, 49, 50, 51, 52 or 53 wherein B is selected from the group consisting of La, Ce, Pr, Nd, Sm, Sb, Sn, Bi, Co, Cr, Ag and mixtures of two or more thereof, and C is selected from the group consisting of K, Mg, Ca and mixtures of two or more thereof.

5 58. The method of claim 46 wherein x is a number ranging from about 0.3 to about 0.85, a is a number ranging from about 0.04 to about 0.5, b is a number ranging from 0 to about 0.1, c is a number ranging from 0 to about 0.1, and d is a number that satisfies valence requirements.

10 59. The method of claim 47 wherein B is selected from the group consisting of La, Ce, Pr, Nd, Sm, Sb, Sn, Bi, Co, Cr, Ag and mixtures of two or more thereof, C is selected from the group consisting of K, Mg, Ca and mixtures of two or more thereof, x is a number ranging from about 0.5 to about 0.8, a is a number ranging from about 0.1 to
15 about 0.5, b is a number ranging from 0 to about 0.1, c is a number ranging from 0 to about 0.1, and d is a number that satisfies valence requirements.

60. The method of claim 51 wherein x is a number ranging from about 0.6 to about 0.8, a is a number ranging from about 0.3 to about 0.4, b is a number ranging from
20 0 to about 0.05, c is a number ranging from 0 to about 0.05, and d is a number that satisfies valence requirements.

61. The method of claim 52 wherein x is a number ranging from about 0.6 to about 0.8, a is a number ranging from about 0.3 to about 0.4, b is a number ranging from
25 0 to about 0.05, c is a number ranging from 0 to about 0.05, and d is a number that satisfies valence requirements.

62. The method of claim 53 wherein x is a number ranging from about 0.6 to about 0.8, a is a number ranging from about 0.3 to about 0.4, b is a number ranging from
30 0 to about 0.05, c is a number ranging from 0 to about 0.05, and d is a number that satisfies valence requirements.

63. The method of claims 46 or 47 wherein b and c are each zero, whereby the reaction zone contains a material comprising a compound having the formula I-A:
 $Ni_xA_aO_d$ (I-A).

64. The method of claim 46 wherein the reaction zone contains a material comprising a compound having the formula (II)



La^* is one or more lanthanide series elements selected from the group consisting of La_m , Ce_n , Pr_o , Nd_p , Sm_q ,

x is a number ranging from about 0.1 to about 0.96,

j, k and l are each numbers ranging from 0 to about 0.8 and the sum of (j + k + l)

is at least about 0.04,

m, n, o, p, q, r, s and t are each numbers ranging from 0 to about 0.1, and the sum of (m + n + o + p + q + r + s + t) is at least about 0.005,

u, v and w are each numbers ranging from 0 to about 0.1, and

d is a number that satisfies valence requirements.

65. The method of claim 64 wherein the sum of (j + k + l) ranges from about 0.04 to about 0.5.

66. The method of claim 64 wherein one of j, k and l are zero, two of j, k and l are greater than zero, and the sum of (j + k + l) ranges from about 0.1 to about 0.4.

67. The method of claim 64 wherein each of j, k and l are greater than zero and the sum of (j + k + l) ranges from about 0.1 to about 0.4.

68. The method of claim 64 wherein the sum of (m + n + o + p + q + r + s + t) ranges from about 0.005 to about 0.1.

69. The method of claim 64 wherein the sum of $(u + v + w)$ is at least about 0.005.

5 70. The method of claim 64 wherein the sum of $(u + v + w)$ ranges from about 0.005 to about 0.1.

71. The method of claim 64 the sum of $(j + k + l)$ ranges from about 0.1 to about 0.4, the sum of $(m + n + o + p + q + r + s + t)$ ranges from about 0.005 to about 0.1, and
10 the sum of $(u + v + w)$ ranges from about 0.005 to about 0.1.

72. The methods of claims 46, 47 or 64 wherein the reaction zone is maintained at a temperature of less than about 300 °C.

15 73. The methods of claims 46, 47 or 64 wherein the alkane is oxidatively dehydrogenated to form the corresponding alkene with an alkane conversion of at least about 10% and an alkene selectivity of at least about 70%.

74. The methods of claims 46, 47 or 64 wherein the catalyst is a supported
20 catalyst, the alkane is selected from the group consisting of ethane, propane, isobutane, n-butane and ethyl chloride, the gaseous oxidant is molecular oxygen, and the reaction zone is maintained at a temperature ranging from about 200 °C to about 400 °C.

75. The methods of claims 46, 47 or 64 wherein the catalyst is a supported
25 catalyst, the alkane is ethane, the gaseous oxidant is molecular oxygen, the reaction zone is maintained at a temperature ranging from about 250 °C to about 350 °C, and the ethane is oxidatively dehydrogenated to form ethylene with an ethane conversion of at least about 10% and an ethylene selectivity of at least about 70%.

30 76. A method for preparing a C_2 to C_4 alkene from the corresponding alkane, the method comprising

providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising (i) a Ni oxide, and (ii) an oxide of an element selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, and Al, and

5 dehydrogenating the alkane to form the corresponding alkene with an alkane conversion of at least about 10% and an alkene selectivity of at least about 70%.

77. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

10 providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a calcination product of a composition comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) an element or compound selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or mixtures of such elements or compounds, and

15 dehydrogenating the alkane to form the corresponding alkene with an alkane conversion of at least about 10% and an alkene selectivity of at least about 70%.

78. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

20 (a) co-feeding a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising a calcination product of a composition comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) an element or compound selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or mixtures of such elements or
25 compounds, the catalyst being at temperature ranging from about 200 °C to about 500 °C,

 (b) contacting the alkane with the catalyst in the presence of the gaseous oxidant to dehydrogenate the alkane to form the corresponding alkene,

 (c) removing alkene, unreacted alkane and unreacted gaseous oxidant from the reaction zone, and

30 (d) effecting steps (a), (b) and (c) for a cumulative reaction period of not less than about 200 hours.

79. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

co-feeding a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising a calcination product of a composition comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) an element or compound selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or mixtures of such elements or compounds,

contacting the alkane with the catalyst in the presence of the gaseous oxidant to dehydrogenate the alkane to form the corresponding alkene, controlling the temperature of the reaction zone to be less than about 300 °C.

80. A method for preparing ethylene from ethane, the method comprising

providing ethane and molecular oxygen to a reaction zone containing a catalyst, the catalyst being a calcination product of a composition comprising (i) a major component consisting essentially of Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) a minor component consisting essentially of an element or compound selected from the group consisting of Ti, Ta, Nb, oxides thereof and salts thereof, or mixtures of such elements or compounds,

maintaining the reaction zone at a temperature ranging from about 275 °C to about 325 °C, and

oxidatively dehydrogenating the ethane to form ethylene with an ethane conversion of at least about 10% and an ethylene selectivity of at least about 70%.

81. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

providing a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane and a gaseous oxidant to a reaction zone containing a catalyst, the catalyst comprising Ni, a Ni oxide, a Ni salt or mixtures thereof, and

oxidatively dehydrogenating the alkane to form the corresponding alkene in the reaction zone, the reaction zone comprising the corresponding alkene in a molar concentration of at least about 5 %, relative to total moles of hydrocarbon, during the oxydehydrogenation, the alkane conversion being at least about 5 %, and the alkene
5 selectivity being at least about 50 %.

82. The method of claim 81 wherein the alkane and the gaseous oxidant are co-fed to the reaction zone, the method further comprising
co-feeding a C₂ to C₄ alkene corresponding to the alkane to the reaction zone.

10

83. The method of claim 81 wherein the alkane and the gaseous oxidant are co-fed to the reaction zone, the method further comprising
exhausting a product stream comprising the corresponding alkene and unreacted alkane from the reaction zone, and

15 recycling at least a portion of the alkene- and unreacted-alkane-containing product stream to the reaction zone.

84. The method of claim 81 wherein the catalyst comprises (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) an element or compound selected from the group
20 consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or mixtures of such elements or compounds.

85. A method for preparing a C₂ to C₄ alkene from the corresponding alkane, the method comprising

25 feeding a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane to a first reaction zone containing a catalyst, the catalyst comprising a calcination product of a composition comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) an element or compound selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or mixtures of such elements or compounds,

30 co-feeding a gaseous oxidant to the first reaction zone,

dehydrogenating the alkane to form the corresponding alkene in the first reaction zone,

exhausting a product stream comprising the corresponding alkene and unreacted alkane from the first reaction zone,

5 feeding the alkene- and unreacted-alkane-containing product stream from the first reaction zone to a second reaction zone,

co-feeding a gaseous oxidant to the second reaction zone,

dehydrogenating the alkane to form the corresponding alkene in the second reaction zone.

10

86. The method of claim 85 wherein the concentration of oxygen in the first and second reaction zones is controlled to obtain an overall alkane conversion of at least about 5 % and an overall alkene selectivity of at least about 50 %.

15

87. The method of claim 85 wherein the molar concentration of oxygen in the first and second reaction zones ranges from about 3 % to about 20 %, in each case relative to ethane.

20

88. The method of claim 85 wherein the second reaction zone comprises the corresponding alkene at a molar concentration of at least about 5 %, relative to total moles of hydrocarbon.

25

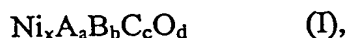
89. The method of claim 85 wherein the alkane is oxidatively dehydrogenated in the first reaction zone to form the corresponding alkene with an alkane conversion of at least about 10% and an alkene selectivity of at least about 70%.

90. The method of claim 85 wherein the alkane is oxidatively dehydrogenated in the second reaction zone to form the corresponding alkene with an alkane conversion of at least about 5% and an alkene selectivity of at least about 50%.

30

91. The method of claim 85 wherein the alkane is oxidatively dehydrogenated in the first reaction zone to form the corresponding alkene with an alkane conversion of at least about 10% and an alkene selectivity of at least about 70%, the second reaction zone comprises the corresponding alkene in a molar concentration of at least about 5 %, relative to total moles of hydrocarbon, and the alkane is oxidatively dehydrogenated in the second reaction zone to form the corresponding alkene with an alkane conversion of at least about 5% and an alkene selectivity of at least about 50%.

92. A mixed-metal oxide composition comprising a compound represented by Formula I



where

A is an element selected from the group consisting of Ti, Ta, Nb, Hf, W, Y, Zn, Zr, Al, and mixtures of two or more thereof,

B is an element selected from the group consisting of a lanthanide element, a group IIIA element, a group VA element, a group VIA element, a group IIIB element, a group IVB element, a group VB element, a group VIB element, and mixtures of two or more thereof,

C is an alkali metal, an alkaline earth metal or mixtures thereof,

x is a number ranging from about 0.1 to about 0.96, a is a number ranging from about 0.04 to about 0.8, b is a number ranging from 0 to about 0.5, c is a number ranging from 0 to about 0.5, and d is a number that satisfies valence requirements.

93. The mixed-metal oxide composition of claim 92 wherein the compound is represented by the Formula II



La* is one or more lanthanide series elements selected from the group consisting of La_m, Ce_n, Pr_o, Nd_p, Sm_q,

x is a number ranging from about 0.1 to about 0.96,

j, k and l are each numbers ranging from 0 to about 0.8 and the sum of (j + k + l)

5 is at least about 0.04,

m, n, o, p, q, r, s and t are each numbers ranging from 0 to about 0.1, and the sum of (m + n + o + p + q + r + s + t) is at least about 0.005,

u, v and w are each numbers ranging from 0 to about 0.1, and

d is a number that satisfies valence requirements.

10

94. A composition of matter comprising a compound resulting from the steps of forming a pre-calcination composition comprising a compound represented by Formula IIA

15 Ni_xTi_jTa_kNb_lLa* Sb_rSn_sBi_tCa_uK_vMg_w (IIA), where

La* is one or more lanthanide series elements selected from the group consisting of La_m, Ce_n, Pr_o, Nd_p, Sm_q,

x is a number ranging from about 0.1 to about 0.96,

20 j, k and l are each numbers ranging from 0 to about 0.8 and the sum of (j + k + l) is at least about 0.04,

m, n, o, p, q, r, s and t are each numbers ranging from 0 to about 0.1, and the sum of (m + n + o + p + q + r + s + t) is at least about 0.005,

25 u, v and w are each numbers ranging from 0 to about 0.1, and d is a number that satisfies valence requirements, and

calcining the pre-calcination composition.

95. A mixed-metal oxide catalyst comprising Ni, a Ni oxide, a Ni salt or mixtures thereof, and

an element or compound selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof and salts thereof, or mixtures of such elements or compounds,

the mixed-metal oxide catalyst being capable of converting at least about 5 % of a C₂ to C₄ alkane or a substituted C₂ to C₄ alkane to the corresponding alkene with an alkane conversion of at least about 10% and an alkene selectivity of at least about 70 % in a reaction zone comprising at least about 5 % of the corresponding alkene.

96. A method for preparing a catalyst composition, the method comprising forming a pre-calcination composition comprising a compound represented by Formula I-B



where

A is an element selected from the group consisting of Ti, Ta, Nb, Hf, W, Y, Zn, Zr, Al, and mixtures of two or more thereof,

B is an element selected from the group consisting of a lanthanide element, a group IIIA element, a group VA element, a group VIA element, a group IIIB element, a group IVB element, a group VB element, a group VIB element, and mixtures of two or more thereof,

C is an alkali metal, an alkaline earth metal or mixtures thereof,

x is a number ranging from about 0.1 to about 0.96, a is a number ranging from about 0.04 to about 0.8, b is a number ranging from 0 to about 0.5, and c is a number ranging from 0 to about 0.5, and calcining the pre-calcination composition.

97. The method of claim 96 wherein the pre-calcination composition comprises a compound represented by Formula II-B



La^* is one or more lanthanide series elements selected from the group consisting of La_m , Ce_n , Pr_o , Nd_p , Sm_q ,

x is a number ranging from about 0.1 to about 0.96,

5 j , k and l are each numbers ranging from 0 to about 0.8 and the sum of $(j + k + l)$ is at least about 0.04,

m , n , o , p , q , r , s and t are each numbers ranging from 0 to about 0.1, and the sum of $(m + n + o + p + q + r + s + t)$ is at least about 0.005,

10 u , v and w are each numbers ranging from 0 to about 0.1, and d is a number that satisfies valence requirements, and calcining the pre-calcination composition.

98. A method for preparing a catalyst, the method comprising

15 forming a pre-calcination composition by a method that includes combining a Ni-component with a first minor component, and optionally with second and third minor components,

the Ni-component consisting essentially of Ni, a Ni oxide, a Ni salt, or mixtures thereof, the molar ratio of the first component ranging from about 0.1 to about 0.96,

20 the first minor component consisting essentially of elements or compounds selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y, Zn, Zr, Al, oxides thereof, and salts thereof, or mixtures of such elements or compounds, the molar ratio of the second component ranging from about 0.04 to about 0.8

25 the second minor component consisting essentially of an element or compound selected from the group consisting of a lanthanide element, a group IIIA element, a group VA element, a group VIA element, a group IIIB element, a group IVB element, a group VB element, a group VIB element, oxides thereof, and salts thereof, or mixtures of such elements or compounds, the molar ratio of the third component ranging from 0 to about 0.5,

30 the third minor component consisting essentially of an element or compound selected from the group consisting of an alkali metal, an alkaline earth metal, oxides

thereof and salts thereof, or mixtures of such elements or compounds, the molar ratio of the fourth component ranging from 0 to about 0.5, and calcining the pre-calcination composition.

5 99. A method for preparing a downstream reaction product of ethylene, the method comprising
 oxidatively dehydrogenating ethane in the presence of a catalyst to form ethylene, the catalyst comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) elements or compounds selected from the group consisting of Ti, Ta, Nb, Co, Hf, W, Y,
10 Zn, Zr, Al, oxides thereof, and salts thereof, or mixtures of such elements or compounds, and

 reacting the ethylene to form the downstream reaction product.

 100. The method of claim 99 wherein ethane is oxidatively dehydrogenated to form
15 ethylene according to the method of claims 1, 23, 46, 76 or 80.

 101. The method of claim 99 wherein the downstream reaction product is selected from the group consisting of polyethylene, styrene, ethanol, acetaldehyde, acetic acid, vinyl chloride, ethylene oxide, ethylene glycol, ethylene carbonate, ethyl acetate and
20 vinyl acetate, and the reaction step is selected, correspondingly, from the group consisting of:

 polymerizing the ethylene to form polyethylene,

 reacting the ethylene with benzene to form styrene, directly or indirectly through an ethylbenzene intermediate,

25 hydrating the ethylene to form ethanol,

 oxidizing the ethylene to form acetaldehyde,

 hydrating the ethylene to form ethanol and then oxidizing the ethanol to form acetaldehyde,

 oxidizing the ethylene to form acetic acid,

30 chlorinating or oxychlorinating the ethylene to form vinyl chloride,

 oxidizing ethylene to form ethylene oxide,

oxidizing ethylene to form ethylene glycol,
oxidizing ethylene to form ethylene oxide, and hydrating the ethylene oxide to
form ethylene glycol,
oxidizing ethylene to form ethylene carbonate, directly or indirectly through an
5 ethylene oxide intermediate,
reacting the ethylene with acetic acid to form ethyl acetate,
reacting the ethylene with acetic acid to form vinyl acetate.

102. A method for preparing a downstream reaction product of propylene, the
10 method comprising
oxidatively dehydrogenating propane in the presence of a catalyst to form
propylene, the catalyst comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and
(ii) elements or compounds selected from the group consisting of Ti, Ta, Nb, Hf, W, Y,
Zn, Zr, Al, oxides thereof, and salts thereof, or mixtures of such elements or compounds,
15 and
reacting the propylene to form the downstream reaction product.

103. The method of claim 102 wherein propane is oxidatively dehydrogenated to
form propylene according to the method of claims 1, 23, 46 or 76.

20

104. The method of claim 102 wherein the downstream reaction product is selected
from the group consisting of polypropylene, propylene oxide, propylene carbonate,
acrolein, acrylic acid and acetone, and the reaction step is selected, correspondingly, from
the group consisting of:

25 polymerizing the propylene to form polypropylene,
oxidizing the propylene to form propylene oxide,
oxidizing the propylene to form propylene carbonate, directly or through a
propylene oxide intermediate,
oxidizing the propylene to form acrolein,
30 oxidizing the propylene to form acrylic acid, and
oxidizing the propylene to form acetone.

105. A method for preparing a downstream reaction product of butane, the method comprising

oxidatively dehydrogenating a butane in the presence of a catalyst to form
5 a butene, the catalyst comprising (i) Ni, a Ni oxide, a Ni salt or mixtures thereof, and (ii) elements or compounds selected from the group consisting of Ti, Ta, Nb, Hf, W, Y, Zn, Zr, Al, oxides thereof, and salts thereof, or mixtures of such elements or compounds, and reacting the butane to form the downstream reaction product.

10 106. The method of claim 105 wherein isobutane is oxidatively dehydrogenated to form isobutylene according to the method of claims 1, 23, 46 or 76.

107. The method of claim 105 wherein the downstream reaction product is selected from the group consisting of butanol, methacrylic acid, butadiene, butanediol,
15 methylethylketone, methylvinylketone, furane, and crotonaldehyde, and the reaction step is selected, correspondingly, from the group consisting of:

hydrating butene to form butanol,

oxidizing isobutene to form methacrylic acid,

dehydrogenating n-butene to form butadiene,

20 dehydrogenating n-butene to form butadiene, and then hydrating the butadiene to form butanediol,

dehydrogenating n-butene to form butadiene, and then oxidizing the butadiene to form methylethylketone,

oxidizing n-butene to form methylethylketone,

25 dehydrogenating n-butene to form butadiene, and then oxidizing the butadiene to form methylvinylketone,

oxidizing n-butene to form methylvinylketone,

oxidizing n-butene to form furane, and

30 dehydrogenating n-butene to form butadiene, and then oxidizing butadiene to form crotonaldehyde.